Spatial disentangling of Greek commercial fisheries landings by gear between 1928-2007

Dimitrios K. MOUTOPOULOS1,2* and Konstantinos I. STERGIOU2

1 Technological Educational Institute of Mesolonghi, Department of Aquaculture and Fisheries, Nea Ktiria, 30200 Mesolonghi, Greece

2 Aristotle University of Thessaloniki, School of Biology, Department of Zoology, Laboratory of Ichthyology, BOX 134, 54124 Thessaloniki, Greece

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In the present study, Greek marine fisheries landings per gear and subarea were reconstructed for the period 1928-2007. The reconstruction was based on the landing per species, gear (i.e., trawls, purse-seines, beach-seines and other small-scale gears operated from vessels with engine power ≥ 19 HP) and subarea during 1990-2007 that have been recorded by the Hellenic Statistical Authority but have never been published or presented before, and the landings from small-scale vessels (with engine power < 19 HP) by prefecture that have been recorded by Agricultural Statistics of Greece during 1970-2007. The results showed that the reconstructed total landings time series, as well as those of each gear separately, increased substantially from 1928 up to mid 1990’s and then declined for the remaining years. The same trend was almost true for the vast majority of the total (i.e. all species combined) landings and of the most abundant species per gear and subarea, depending on each case. This indicates that the general trend identified were not the result of aggregating landings over different gears and subareas but rather a general pattern for most gears, subareas and dominant species. Apart from studying the historical development of the Greek fisheries, the main reason for reconstructing Greek fisheries landings was to use this series for applying various ecological indices/analyses on a gear/subarea basis and to develop ecosystem-based models for comparing different management scenarios for Greek waters.

Key words: fisheries landings, landings reconstruction, long-term trends, multi-gear fisheries, fisheries history, Mediterranean.

INTRODUCTION

Greek fisheries statistics for 1928-2007 have been collected by various organisations (for an extended discussion see Moutopoulos & Stergiou, 2011), and those of the Hellenic Statistical Authority (HELSTAT, previously known as National Statistical Service of Greece, NSSG) are more robust, reliable and consistent (for a discussion see: Stergiou et al., 1997; Papaconstantinou et al., 2002; Tsikiras et al., 2007).

HELSTAT marine fisheries statistics have been recorded and published in annual bulletins covering two different periods: 1928-1939 (GSSG, 1934-1940) and 1964 to present (HELSTAT, 1966-2009). The available data included, among others (see Stergiou et al., 1997 for a full description), fisheries landings per species and fishing subarea (i.e. Greek waters are spatially allocated to 16 fishing subareas, see Fig. 1) which have been presented elsewhere (for 1928-1939: Moutopoulos & Stergiou, 2011; for 1964-2003: Stergiou et al., 2007). During 1969-2007, fisheries landings were recorded for professional fishing vessels with engine power ≥ 19 HP (henceforth called large vessels), whereas during 1964-1969 landings were recorded from all engined-vessels. The landings from vessels with engine power < 19 HP (henceforth called small vessels) are recorded for 41 prefectures (Fig. 1) by a different branch of HELSTAT, namely Agricultural Statistics of Greece (ASG) (ASG, 1977-2009). Tsikiras et al. (2007) reconstructed the total (i.e.
all subareas combined) landings during 1964-2004 after the inclusion of landings from small vessels and estimates of landings from certain large pelagic species (i.e. *Auxis thazard*, *Euthynnus alletteratus*, *Thunnus* spp. and *Xiphias gladius*) that were taken from FAO. Moutopoulos & Stergiou (2011) presented the landings per species during 1928-1939, which were recorded by GSSG, re-allocated the spatial distribution of landings from 29 custom port authorities to 15 HELSTAT subareas and summarized the total landings from different sources for Greek waters during 1928-2007.

In the present study, the species landings by gear and subarea (including the landings from small vessels by subarea) were disaggregated in order to obtain a continuous reconstructed time series of marine fisheries landings per gear and subarea during 1928-2007. Our reconstructed landings refer only to commercial landings (i.e. they do not include discards, illegal and unreported catches as well as recreational fisheries landings).

The reconstruction was based on the landing per species, gear (i.e. trawls, purse-seines, beach-seines and small-scale gears) during 1928-1989 using the data shown in Tables 1 and 2 and based on the methodology described in Tables 3 and 4. The final reconstruction of the Greek fisheries landings during 1928-2007 was derived by summing the following final matrices (for symbols, see Tables 3 and 4):

\[
\]

The above information will be a valuable repository of knowledge for studying the effects of fishing on marine ecosystems (Zeller & Pauly, 2006), useful for re-evaluating the state of Greek fisheries and for comparing with global fisheries trends (Pauly, 2008) and will be the basis for developing mass-balanced models (e.g. Pauly *et al.*, 2000) for the Greek Seas and testing various management scenarios (Moutopoulos *et al.*, unpublised data).

**MATERIALS AND METHODS**

Greek fisheries landings per species were disaggregated for each of the 16 fishing subareas (Fig. 1) and gear (trawls, purse-seines, beach-seines and small-scale gears) during 1928-1989 using the data shown in Tables 1 and 2 and based on the methodology described in Tables 3 and 4. The final reconstruction of the Greek fisheries landings during 1928-2007 was derived by summing the following final matrices (for symbols, see Tables 3 and 4):


Detailed landings per species/gear/subarea for 1928-2007 are presented in Table S5 (see online sup-
<table>
<thead>
<tr>
<th>Code</th>
<th>Period</th>
<th>Fishery type</th>
<th>Species resolution</th>
<th>Gear type</th>
<th>Spatial resolution (Fig. 1)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1928-1939</td>
<td>Marine</td>
<td>33 fish species, 3 cephalopod species, 3 crustacean species and 1 other cephalopod and crustacean species group</td>
<td>All gear types (i.e. trawl, purse seine, beach seine and small scale) combined for all engined vessels</td>
<td>For 15 fishing subareas</td>
<td>GSSG (reconstructed by Moutopoulos &amp; Stergiou, 2011)</td>
</tr>
<tr>
<td>B</td>
<td>1940-1949</td>
<td>All fisheries (i.e., marine*, freshwater and lagoons) combined</td>
<td>Total landings (i.e. all species combined)</td>
<td>All gear types combined for all engined vessels</td>
<td>Total for Greek waters</td>
<td>Ananiadis (1968)</td>
</tr>
<tr>
<td>C</td>
<td>1950-1957</td>
<td>All fisheries combined (i.e., marine*, freshwater, lagoons and overseas)</td>
<td>18 fish species, 1 cephalopod species and 1 crustacean species</td>
<td>All gear types combined for all engined vessels</td>
<td>Total for Greek waters</td>
<td>FAO</td>
</tr>
<tr>
<td>D</td>
<td>1958-1963</td>
<td></td>
<td>27 fish species, 1 cephalopod species and 2 crustacean species</td>
<td>All gear types combined for all engined vessels</td>
<td>Total for Greek waters</td>
<td>FAO</td>
</tr>
<tr>
<td>E</td>
<td>1964-1969</td>
<td></td>
<td>17 fish species, 4 cephalopod species and 1 crustacean species</td>
<td>All gear types combined for all engined vessels</td>
<td></td>
<td>FAO</td>
</tr>
<tr>
<td>F</td>
<td>1964-1969</td>
<td></td>
<td>Total landings (all species combined)</td>
<td>Per gear type (i.e. trawl, purse-seine, beach-seine and other small-scale) for all engined vessels</td>
<td>For 16 fishing subareas</td>
<td>NSSG</td>
</tr>
<tr>
<td>G</td>
<td>1964-2007</td>
<td></td>
<td>Auxis thazard, Euthynnus alletteratus, Thunnus spp. and Xiphias gladius</td>
<td>All gear types combined for all engined vessels</td>
<td>Total for Greek waters</td>
<td>ICCAT</td>
</tr>
<tr>
<td>H</td>
<td>1970-1981</td>
<td>Marine</td>
<td>17 fish species, 4 cephalopod species and 1 crustacean species</td>
<td>All gear types combined excluding small vessels</td>
<td></td>
<td>FAO</td>
</tr>
<tr>
<td>I</td>
<td>1970-1989</td>
<td></td>
<td>Total landings (all species combined)</td>
<td>Per gear type (i.e. trawl, purse-seine, beach-seine and other small-scale) excluding small vessels</td>
<td>For 16 fishing subareas</td>
<td>NSSG</td>
</tr>
<tr>
<td>J</td>
<td>1982-1989</td>
<td></td>
<td>56 fish species, 5 cephalopod species and 5 crustacean species</td>
<td>All gear types combined excluding small vessels</td>
<td></td>
<td>NSSG unpublished data (Nasiakou A, pers. comm.)</td>
</tr>
<tr>
<td>K</td>
<td>1990-2007</td>
<td></td>
<td>56 fish species, 5 cephalopod species and 5 crustacean species</td>
<td>Per gear type (i.e. trawl, purse-seine, beach-seine and other small-scale) excluding small vessels</td>
<td></td>
<td>NSSG unpublished data (Nasiakou A, pers. comm.)</td>
</tr>
</tbody>
</table>

* Marine landings were estimated by the proportion (equal to 0.735) of the Greek marine landings to the total (i.e. marine, lagoons and freshwater, excluded the landings from overseas) landings in 1939 (GSSG, 1934-1940).

* Marine landings were estimated by the proportion (equal to 0.840) of the Greek marine landings to the total (i.e. marine, lagoons and freshwater, excluded the landings from overseas) landings in 1956 from data published by Ananiadis (1968).
TABLE 2. Summary of the fishing statistics recorded for the small vessels by the different statistical organizations for Greek marine waters, (1964-2007)

<table>
<thead>
<tr>
<th>Legend</th>
<th>Period</th>
<th>Data</th>
<th>Spatial resolution (Fig. 1)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>1975-1994</td>
<td>Mean total (i.e. for all fish, cephalopod, crustacean and bivalve species*) annual landings per vessel</td>
<td>Total for Greek waters</td>
<td>ASG</td>
</tr>
<tr>
<td>M</td>
<td>2002-2006</td>
<td>Total (i.e. for all fish, cephalopod, crustacean and bivalve species*) annual landings per vessel</td>
<td>For 41 prefectures</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>1970-1974</td>
<td>Total for Greek waters</td>
<td></td>
<td>Tsikiras et al. (2007)</td>
</tr>
<tr>
<td>O</td>
<td>1975-2006</td>
<td>Number of small vessels</td>
<td></td>
<td>For 41 prefectures ASG</td>
</tr>
</tbody>
</table>

* Bivalve species were excluded from the reconstruction of the fisheries landings from both large-engined and small-engined vessels, from which a large proportion of the reported values are derived from intensive farming in coastal sea (Galinou-Mitsoudi et al., 2006)
TABLE 3. Methodology for the reconstruction of fisheries landings from vessels with engine power < 19 HP (1970-2007)

<table>
<thead>
<tr>
<th>Method used</th>
</tr>
</thead>
<tbody>
<tr>
<td>From matrix O (for the period 1975-1990) (Table 2), bootstrapped mean (1975-1990) proportions of the number of small vessels for each of the 41 prefectures were estimated, Q1</td>
</tr>
<tr>
<td>Number of small vessels for each of the 41 prefectures (1970-1974), Q2 = Q1 \cdot N (Table 2)</td>
</tr>
<tr>
<td>Number of small vessels for each of the 41 prefectures (1970-1990), Q3 = Sum of the matrices Q2 and O (Table 2)</td>
</tr>
<tr>
<td>Number of small vessels for each of the 16 subareas (1970-1990), Q4, was derived from the spatial allocation of the online supplementary material, Table S3 to the 16 subareas as shown in the online supplementary material, Table S1</td>
</tr>
<tr>
<td>Number of small vessels for each of the 16 subareas (1991-2007), Q5, was derived from the spatial allocation of matrix P1 (Table 2) to the 16 subareas as shown in the online supplementary material, Table S2</td>
</tr>
<tr>
<td>Number of small vessels for each of the 16 subareas (1970-1990), Q6, = Sum of the matrices Q4 and Q5</td>
</tr>
<tr>
<td>Mean annual landings of small vessels for each of the 41 prefectures (2002-2006), Q7 = bootstrapped mean (2002-2006) proportions of landings for all species combined for each of the 41 prefectures were estimated from matrix M (Table 2)</td>
</tr>
<tr>
<td>Landings of small vessels for each of the 16 subareas (2002-2006), Q8, were derived from the spatial allocation of Q7 to the 16 subareas according with the online supplementary material, Table S2</td>
</tr>
<tr>
<td>1970-1994: Mean total (i.e. all species combined) landings/subarea, Q9 = L (see Table 2) \cdot Q6 (for the period 1970-1994)</td>
</tr>
<tr>
<td>1995-2007: Total (i.e. all species combined) landings/subarea, Q10 = Q8 \cdot Q6 (for the period 1995-2007)</td>
</tr>
<tr>
<td>1970-2007: Total (i.e. all species combined) landings/subarea, Q11 = Q9 + Q10</td>
</tr>
<tr>
<td>Q11 was taxonomically disaggregated by species based on Anonymous (2001) using the mean (1996-2001) catch per unit of effort for 66 species(^2) caught by all small-scale gears in five Greek sea regions (see online supplementary material, Table S1). The spatial disaggregation of S11 by species to the 16 subareas is based on the region-subarea relationship shown in the online supplementary material, Table S1</td>
</tr>
</tbody>
</table>

\(^1\) For the estimation of the number of small vessels during 1991-2007, the number of small vessels registered in Common Fisheries Registry (CFR) was used instead of the those reported by ASG. This is due to the fact that CFR records all the officially registered vessels in Greek waters which derived from local custom port authorities (EC, 1998), whereas ASG uses a random sampling technique.

\(^2\) For large pelagics (i.e. *Auxis thazard*, *Euthynnus alletteratus*, *Thunnus* spp. and *Xiphias gladius*) derived from small vessels we multiplied the landings estimated in Anonymous (2001) with 0.454. This is because the official records of the Ministry of Agricultural and Food for 2006, the vessels with engine power < 19 HP and vessel length < 10 m licensed to catch large pelagic were 45.4% of the total number of licensed vessels involved in the large pelagics fisheries.
### TABLE 4. Methodology for the reconstruction of marine fisheries landings from vessels with engine power ≥ 19 HP from data recorded by the different organizations and periods for Greek waters (1928-2007) according to HELSTAT (Hellenic Statistical Authority)

<table>
<thead>
<tr>
<th>Method used</th>
<th>Spatial-gear disaggregation</th>
</tr>
</thead>
<tbody>
<tr>
<td>From matrix K (Table 1), bootstrapped mean (1990-2007) proportions for each of 65 species landings per gear (i.e. trawls, purse-seines, beach-seines and other small-scale gears with engine power &lt;19 HP) were estimated for each subarea, T1</td>
<td>Landings for 65 species/subarea/gear (1990-2007), K (Table 1)</td>
</tr>
<tr>
<td>From the sum of matrices K + Q11 (for 1990-2007) (Table 3), bootstrapped mean (1990-2007) proportions for each of 65 species landings per gear were estimated for each subarea, T2</td>
<td></td>
</tr>
<tr>
<td>In matrix H (Table 1), species that were reported as aggregated groups for each of the 16 subareas, during 1964-1981 (see online supplementary material, Table S3) and were reported as individual species during 1982-1989, were disaggregated into individual species landings per subarea, during 1964-1981, according to Tsikliras et al. (2007), T3</td>
<td>Landings for 65 species/subarea/gear (1970-1989), Z1 = T5 \cdot T1 \cdot I (Table 1)</td>
</tr>
<tr>
<td>In matrix H (Table 1), species that were reported as aggregated groups together with the landings of “other Osteichthyes group”, during 1964-1981 (see online supplementary material, Table S4) and were reported as individual species landings, during 1982-1989, were disaggregated into individual species landings for each of the 16 subareas, during 1964-1981, T4</td>
<td>Landings for 65 species/subarea for all gears combined (1964-1989), T5 = species landings of the matrices T3 and T4 were correspondingly conjuncted with matrices E, H and J (Table 1)</td>
</tr>
<tr>
<td>Mean (1982-2007) proportion of landings of the large pelagics in each of the 16 subareas for all gears combined, T6 = was estimated from the matrices J and K (Table 1)</td>
<td>Landings for large pelagics/subarea for all gears combined (1982-2007), Z3 = T6 \cdot G (for 1982-2007) (Table 1)</td>
</tr>
<tr>
<td>Mean (1964-1981) proportion of landings of the large pelagics in each of the 16 subareas for all gears combined, T7 = was estimated from the matrices E and H (Table 1)</td>
<td>Landings for large pelagics/subarea/gear (1982-2007), Z4 = Z3 \cdot T1</td>
</tr>
<tr>
<td>Mean (1964-1969) proportions for each of 65 species landings (as taxonomically disaggregated above) in each of the 16 subareas for all gears combined, T8 = were estimated from matrix E (Table 1)</td>
<td>Landings for large pelagics/subarea for all gears combined (1964-1981), Z5 = T7 \cdot G (for 1964-1981) (Table 1)</td>
</tr>
<tr>
<td>Mean (1964-1969) proportions of all species combined for each gear in each of the 16 subareas, T9 = were estimated from matrix F (Table 1)</td>
<td>Landings for large pelagics/subarea/gear (1964-1981), Z6 = Z5 \cdot T2</td>
</tr>
</tbody>
</table>
TABLE 4. continued

<table>
<thead>
<tr>
<th>Method used</th>
<th>Spatial-gear disaggregation</th>
</tr>
</thead>
</table>
| In matrices C and D (Table 1), species (see online supplementary material, Table S3) that were reported as aggregated groups during 1950-1963 and were reported as individual species during 1964-2007, were disaggregated into individual species landings per 16 subareas, during 1950-1963 using the methodology of Tsikliras et al. (2007), T10 | Landings for 43 species/subarea for all gears combined (1950-1963), Z7 = T12 ⋅ T8  
Landings for 43 species/subarea/gear (1950-1963), Z8 = Z7 ⋅ T2 ⋅ T9       |
| In matrix C (Table 1), species (see online supplementary material, Table S4) that were reported as aggregated groups together with the landings of “other Osteichthyes group”, during 1950-1957 and were reported as individual species landings during 1958-1963 (matrix D: Table 1), were disaggregated into individual species landings, during 1950-1957, T11 | Landings for 40 species/subarea for all gears combined (1940-1947), Z9 = B (Table 1) ⋅ T13  
Landings for 40 species/subarea (15 subareas)/gear (1940-1947), Z10 = Z9 ⋅ T2 ⋅ T9  
Landings for 40 species/subarea (16 subareas) for all gears combined (1948-1949), Z11 = B (Table 1) ⋅ T8  
Landings for 40 species/subarea (16 subareas)/gear (1948-1949), Z12 = Z11 ⋅ T2 ⋅ T9 |
| Landings for 43 species in all subareas and gears combined (1950-1963), T12 = the species landings of the matrices T10 and T11 were correspondingly conjuncted with matrices C and D (Table 1) | From matrix A (Table 1) the mean (1936-1939) proportions of the marine landings for each of 40 species landings for all gears combined were estimated for each of the 15 subareas, T13 |
| Landings for 40 species/subarea (15 subareas)/gear (1928-1959), Z13 = A (Table 1) ⋅ T2 ⋅ T9 |  

1 Iterative (100 times) bootstrap technique were used by removing the landings from each year at each time-step. Given that the produced means will be used to hindcast the landings, we assumed that the probability for data to be removed from each year at each time-step increased linearly with time (during 1990-2007) and the landings from more recent years, which overall weighted less, were most frequently eliminated

2 The mean (1982-1986) proportion of landings for the species that were included in the “other Osteichthyes” group landings during 1964-1981 were estimated. This proportion was multiplied with the annual landings for the “other Osteichthyes” group during 1964-1981 (matrices E and H: Table 1) and with the proportion of the contribution of the “other Osteichthyes” group to the mean (1982-1986) contribution of landings from the “other Osteichthyes” group together with the species that were reported aggregated with this group during 1964-1981. The 1982-1986 period was selected because the landings of the “other Osteichthyes” group remained quite stable (Fig. 4a)

3 Matrices F, I and T9 were used as weighted factors

4 The mean (1958-1960) proportion of landings for the species that were included in the “other Osteichthyes” group landings during 1950-1957 were estimated. This proportion was multiplied with the annual landings for the “other Osteichthyes” group during 1950-1957 (matrix C: Table 1) and with the proportion of the contribution of the “other Osteichthyes” group to the mean (1958-1960) contribution of landings from “other Osteichthyes” group together with the species that were reported aggregated with this group during 1950-1957. The 1958-1960 period was selected because the mean proportion of the “other Osteichthyes” group remained quite stable (about 15%)

5 HELSTAT subarea S16 (Dodecanese Islands) was annexed by Greece in 1948
plementary material, Table S5). Different types of time-varying regressions (i.e. linear, quadratic, exponential: trend analysis) (Stergiou & Christou, 1996) were fitted to the reconstructed landings time series of the different gears and for the dominant species per gear (i.e. those with the highest mean percentage contribution during 1928-2007). Best models were selected based on the value of the coefficient of determination (R²) and regressions and slopes that were significantly different from 0 (p < 0.05) were identified. Finally, the pelagic/demersal ratio (P/D) was also estimated for total (i.e. all subareas and gears combined) landings during 1928-2007.

RESULTS

Total reconstructed landings

Greek total (i.e. all species/subareas/gears combined) reconstructed landings derived from all engined-vessels increased by 2206% between 1928 and 2007, ranging from 6073 tn (in 1928) to 133964 tn (in 2007), with a maximum of 193256 tn, in 1994 (Fig. 2A).

Reconstructed total annual landings for each gear (Fig. 2B) showed a gradual increase during 1928-1994, with small-scale vessels exhibiting a much steeper increase (slope values = 0.059) than those of the remaining 3 gears (slope values; trawlers: 0.031, purse-seiners: 0.039 and beach-seiners: 0.040). Since 1995, purse-seine, beach-seine and small-scale landings gradually decreased (by 48.1%, 23.9% and 18.5%, respectively). In contrast, trawl landings decreased during 1994-1999 and then increased again almost to the mid-1990s level.

The percentage contribution of each gear to the total landings during 1964-2007, the period during which landings were reconstructed (black circles in Fig. 2A), is shown in Figure 2C. The percentage contribution of purse-seiners and beach-seiners gradually decreased during 1964-2007 (from 46.6% and 13.4% to 19.5% and 2.7%, respectively), whereas those of trawlers decreased during 1964-1999 (from 20.7% to 11.9%) and then increased again to the mid-1960s level (20.2% for 2007). In contrast, the percentage contribution of small-scale landings gradually increased...
from 21.3% (in 1928) to 57.3% (in 2007), with a maximum of 62.3% in 1999 (Fig. 2C). The percentage contribution of the landings of small vessels (those recorded by ASG), increased from 25.6% (in 1970) to 32.5% (in 2007), with a maximum of 37.8%, in 2001.

The P/D ratio (Fig. 2D) remained stable during 1928-1949, fluctuating around 1.66, and increased to 2.76 in 1954 and then gradually decreased to 0.83, in 2007, with a minimum value of 0.76, in 2003.

**Reconstructed landings per fishing subarea and gear**

Annual total landings per subarea and gear during 1928-2007 are shown in Figure 3. More than 50% of the time-series exhibited an exponential positive trend (35 out of 64 time series), whereas 19 out of the 64 landings series exhibited a quadratic trend, nine landings series a linear increasing trend and one landings series a non-significant trend (that for subarea S9 for trawlers).

Landings from trawlers and other small-scale vessels generally peaked during 1990-1999 for most fishing subareas, whereas those from beach-seiners and purse-seiners peaked over an extended period (1965-1999), depending on subarea (Fig. 3).

In subarea S12, three out of the four fishing gears (i.e. trawlers, purse-seiners and small-scale vessels) landings contributed equally to the total landings, whereas those from beach-seiners and purse-seiners peaked over an extended period (1965-1999), depending on subarea (Fig. 3).

In subarea S12, three out of the four fishing gears (i.e. trawlers, purse-seiners and small-scale vessels) landings contributed equally to the total landings, while, purse-seine landings dominated in subareas S8, S11, S13 and S14 and small-scale vessel landings in all the remaining subareas (Fig. 3).

**Trends in the landings of the dominant species per subarea and gear**

The species dominating the landings of each gear varied with subarea (Fig. 4). Thus, for trawlers, Spicara smaris was the dominant species in eight subareas (central-south Ionian and Aegean Seas: S5, S6, S7, S10, S12, S15, S17 and S18), Merluccius merluccius and Mullus barbatus each in two subareas, and S. flexuosa, Trachurus mediterraneus, Engraulis encrasicolus and Natantia each in one subarea (Fig. 4). For purse-seiners, Sardina pilchardus and E. encrasicolus dominated the landings each in six subareas (S3-S6/S14-S15 and S8-S13, respectively), Boops boops in three subareas (south Aegean: S7, S17, S18) and Scomber japonicus in S16. For beach-seiners, S. smaris dominated the landings in all subareas except in the Thracian Sea (S14), where landings where dominated by S. pilchardus. Finally, for small-scale vessels, B. boops was the dominant species in four subareas (south Ionian and central-south Aegean Seas: S7, S8, S12 and S17), Mugilidae, S. pilchardus and M. merluccius in three subareas each (S10, S11 and S15; S4, S13 and S14; S3, S5 and S9, respectively) and Dentex macrophthalmus and X. gladius in one subarea each (Cretan Sea: S18, and south Ionian: S6, respectively) (Fig. 4).

The landings of the most abundant species per subarea and gear exhibited variability and 61 out of 64 landings series displayed significant (\(p < 0.05\)) trends during 1928-2007 (Fig. 4). Species landings from trawlers and purse-seiners mostly exhibited significant (\(p < 0.05\)) exponential (for 6 out of 16 cases for each gear) and quadratic (for 9 and 8 cases, respectively) trends, whereas very few exhibited non significant trends (for 1 and 2 cases, respectively). Species landings from beach-seiners mostly exhibited significant (\(p < 0.05\)) quadratic trends (for 12 out of 16 cases), followed by exponential trends (in 4 cases). Species landings from small-scale vessels mostly exhibited significant (\(p < 0.05\)) exponential trends (for 12 out of 16 cases), in three cases linear increasing trends and in one case a quadratic trend.

**DISCUSSION**

In the present study, we reconstructed Greek commercial fisheries landings by gear and subarea for an extended period and built a time series of total commercial landings for 1928-2007. We also reconstructed the landings for 75 species, depending on the periods (see online supplementary material, Table S4), for four gears and 16 subareas during for 1928-2007 (i.e. overall 4800 time series), all available in the online supplementary material (see online supplementary material, Table S5). A similar compilation/reconstruction of fishing effort by gear is also in progress (Moutopoulos et al., unpublished data). The main reason for doing such a reconstruction was, apart from evaluating the historical development of the Greek fisheries (see also Moutopoulos & Stergiou, 2011), to: (a) evaluate the status of the Greek fisheries using various ecological indices/analyses on a gear/subarea basis (e.g. Marine Trophic Index: Pauly & Watson, 2005; Fisheries in Balance Index: Pauly et al., 2000; trophic spectra analysis: Libralato & Soldoro, 2010; pelagic/demersal ratios: Enin & Groger, 2004) and fisheries indices/analyses (e.g. catch-effort models: Hilborn & Walters, 1992) and (b) develop mass-balanced models (Ecopath with Ecosim; Pauly et al., 2000) in order to outline the potential effects of multi-species and multi-gear fisheries in a ecosystem-
FIG. 3. Annual total (i.e. all species combined) landings per gear (i.e. trawls, purse- and beach-seines and small-scales) and fishing subarea (subarea numbers followed Fig. 1), Greek waters, 1928-2007. Significant ($p < 0.05$) trends are also shown. Numbers indicated mean (± s.e.) % contribution of landings per subarea.
FIG. 4. Annual species landings for the most abundant species per gear-subarea, Greek waters, 1928-2007. Significant ($p < 0.05$) trends are also shown. Numbers indicated mean ($\pm$ s.e.) % contribution of landings per gear-subarea.
based context and, thus, to evaluate different management scenarios for Greek waters. Disentangling landings by gear on fine spatial scales is important because it reduces the bias in estimates of various ecological indices (Pauly & Palomares, 2005) that might lead to false conclusions about the state of fisheries (Pauly, 2008).

The pattern of the total (i.e. all species/gears/sub-areas) reconstructed landings during 1928-2007 differs from the one presented in Moutopoulos & Stergiou (2011) in that it includes the landings of small vessels per subarea for the period 1970-2007. However, the reconstructed total landings time series (Fig. 2A) as well as those of each gear separately (Fig. 2B), parallels the pattern shown in Moutopoulos & Stergiou (2011). The latter authors identified four different phases in the development of the Greek fisheries: 1928-1946 (pre-development phase), 1947-1969 (growth phase), 1970-1994 (fully to over-exploited phase) and 1995-2007 (collapse phase). Our present analysis also showed that the general trend for the vast majority of the total (i.e. all species combined) landings per gear and subarea (Fig. 3) and of the most abundant species per gear and subarea (Fig. 4), was an increase from 1928 up to mid 1980s-mid 1990s followed by a decline for the remaining years, depending on each case, which generally agrees with that of the total landings.

This general pattern indicates that the different phases identified in Moutopoulos & Stergiou (2011) were not the result of aggregating landings over different gears and subareas but rather a general pattern for most gears, subareas and dominant species. Thus, the increasing trend of landings during the ‘fully to over-exploited’ phase (1970-1994), which is attributed to the fleet modernization and geographic/bathymetric expansion of the fisheries (Papakonstantinou & Farrugio, 2000; Anonymous, 2001; Moutopoulos & Stergiou, 2011) was followed by a general decline of landings because fisheries have become unsustainable, independently of gear type and subarea. It is interesting to note that the first sign of overexploitation in Greek waters seem to have already occurred in the early 1950’s, especially in enclosed gulfs where most of fishing exploitation was concentrated during that period (Ananiadis, 1970). For instance, during 1949-1956 both the experimental landings and landings per fishing effort of trawlers for M. barbatus and M. merluccius decreased with time in the enclosed gulfs of subareas S8, S13 and S14 (Ananiadis, 1970). Later, several field studies have shown that some of the most commercially important demersal species in Greek waters (i.e. M. merluccius, M. barbatus, Pagellus spp.) are also overexploited (Stergiou et al., 1997; Poliotou, 2007). Small pelagic fish are also considered to be overexploited (i.e. E. encrasicolus: Machias et al., 2007 and S. pilchardus: Voulgaridou & Stergiou, 2003) and the same is true of large pelagic species (i.e. X. gladius and Thunnus thynnus: ICCAT, 2003). In addition, the overall mean trophic level of the landings of the species with trophic level > 3.5 in Greek waters declined (fishing down) during 1995-2007 (Stergiou, 2005).

Notable exceptions to the above-mentioned pattern of landings evolution were the trawl landings in S14 and S17, where landings continued to increase, the purse-seine landings in S10, where landings increased in the last years, the beach-seine landings in S4, where landings sharply increased in the last years, and the small-scale landings in S10 and S13, where again landings continued to increase. With respect to the landings of the most abundant species per gear and subarea, the exceptions were E. encrasicolus (for purse-seiners in S10 and trawlers in S11), M. merluccius (for trawlers in S14), Mugilidae (for small-scale vessels in S10) and S. smaris (for beach-seiners in S4, for trawlers in S10 and S17), all of which increased during the collapse phase.

Such exceptions might be related to the effect of one or more of the following factors: (a) fisheries legislation changes (i.e. various technical measure most of which were established since 1953: Gonzalvo et al., 2011; Moutopoulos & Stergiou, 2011), (b) eutrophication changes (i.e. originated either from the Black Sea, influencing the northern-central Aegean waters: see Stergiou et al., 1997; Nikolaidis et al., 2005, or locally in enclosed gulfs with limited water renewal, in S4, S10: Stergiou et al., 1997; Ferentinos et al., 2010), which generally enhance fisheries productivity, especially for small-pelagics (Caddy & Garibaldi, 2000), (c) technological changes (Adamidou, 2007) and (d) climatic changes (Tsikiras, 2008; Corsini-Foka, 2009). However, the small number of such exceptions indicates that they are probably related to local fishing operations and/or other reasons. This is because the four general factors mentioned above would have affected many more cases of gear and species landings. This requires the analysis of the landings of each species participating in the landings per gear and subarea, which is outside the scope of the present paper. There are only two cases that need to be stressed here.
Firstly, the trawl landings in the enclosed and relatively shallow subarea S11 (depth < 100 m) increased, mostly because of the increase of *E. encrasicolus* landings, in the last years (Fig. 3). Trawl landings represented a very small part of the total landings in S11 because of the all year ban on trawling since 1967 (No 1 Royal Decree 50/67). Thus, trawl landings should have been zero because of this ban. The non-zero landings must be attributed to the multiple licensing system, according to which the same vessel operates as trawler outside S11 and as purse-seiner within S11, a fact that probably leads to local misreporting.

The second case refers to the increasing trend for beach-seine landings in S4, as opposed to all other subareas in which beach-seine landings decline because of the gradual withdrawal of this gear (see below). Trawl and purse-seine fishing is banned in a large part of S4 (i.e. the enclosed Amvrakikos gulf) since 1966 (No 8 Royal Decree 917/66) and 1953 (No A81 Royal Decree 23.3/8-4-53), respectively. In addition, the eutrophication of the Amvrakikos gulf has increased in recent years (Ferentinos et al., 2010). These two factors probably resulted in an increase in the populations of *S. pilchardus*, *S. smaris* and *B. boops* and this is probably reflected in the increase of the beach-seine landings for these species during recent years.

The low values of the percentage contribution per gear (Fig. 2C) stressed the fact that the parameters used for reconstruction are not varying a lot, thus reconstruction is feasible and robust. The decreasing contribution of beach-seine landings (Fig. 2C) is attributed to the gradual withdrawal of beach-seiners from Greek waters, which started in 1980 (Papaconstantinou & Farrugio, 2000) and will end with the complete banning in 2013 (ER 1967/2006) as this gear (Fig. 2C) stressed the fact that the parameters used for reconstruction are not varying a lot, thus reconstruction is feasible and robust. The decreasing contribution of beach-seine landings (Fig. 2C) is attributed to the gradual withdrawal of beach-seiners from Greek waters, which started in 1980 (Papaconstantinou & Farrugio, 2000) and will end with the complete banning in 2013 (ER 1967/2006) as this gear is considered to be harmful for both the stocks (Stergiou et al., 1996) and habitats (Katsanevakis et al., 2010). Thus, through EU fundings, 30.6% of beach-seiners have been withdrawn from Greek waters during 1991-2007 (Katsanevakis et al., 2010). The increasing contribution of trawl landings during late 1980’s is most probably attributed to the fleet modernization and geographic expansion of the trawl fisheries (Papaconstantinou & Farrugio, 2000; Anonymous, 2001). In addition, the gradual withdrawal of beach-seiners, which exploit the same demersal and inshore species as trawlers do (Stergiou et al., 1996), left room for the ‘expansion’ of trawling.

The decreasing contribution of purse-seiners to the total landings during 1964-2007 might be attributed to the decline in the abundance of small and large pelagic species in recent years (as mentioned above) and mainly to the steep increase of the landings of small-scale vessels and trawlers, which both exploit demersal and inshore species (Stergiou & Petrakis, 1993). As a result, the P/D ratio declined considerably, illustrating the shift from pelagic to demersal dominance in landings (dashed line in Fig. 2D).

The very steep increase in the contribution of small-scale vessels to the total landings during 1964-1999 is attributed to their modernization (Papaconstantinou & Faruggio, 2000), which allowed vessels to fish in more distant and deep waters than before, that lead to a gradual engagement of small-scale vessels into fishing for large pelagic and benthopelagic species (Anonymous, 2001). The high percentage contribution of the small-scale landings as a total (Fig. 2C) as well as for most fishing subareas highlights their significant importance for Greece and is a factor differentiating Greece from other European countries (Tzanatos et al., 2006). Thus, the next step of future research should be the disentangle of small-scale landings into their constituent gear components (i.e. netters and longliners).

It is important to note that a significant part of the small-scale landings usually are directed to the local market, hotels and restaurants (Tzanatos et al., 2006), without passing through the wholesale market. Thus, it is quite probable that small-scale landings are highly underestimated and the illegal, unreported and unregulated (IUU) (Tinch et al., 2008) part of the small-scale catches is probably very high. Thus, accurate estimates of IUU catches are very important for the management of Greek resources, and require urgent attention in terms of proper and regular estimation.

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**ONLINE SUPPLEMENTARY MATERIAL**

Supplementary data associated with this research paper are presented on the online version of this manuscript (www.jbr.gr).
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